Basin Size is the Magic Knob for Controlling Costs of RDII Reduction Projects

Patrick Stevens, P.E.
ADS Environmental Services
1300 Meridian Street, Suite 3000
Huntsville, AL 35801
256 430 6558
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ABSTRACT

The Pareto Principle states generally that most things in nature are not uniformly distributed and the majority of occurrences appear in a minority of events. This observation is often stated as the '80/20' Rule. This means for example that 80% of the revenue from a grocery store comes from 20% of the items or that 80% of software use comes from 20% of its features. Originally, the Pareto Principle referred to Vilfredo Pareto's observation that 80% of Italy's wealth belonged to only 20% of the population.

Our historical approach to removing Rainfall Dependent Infiltration/Inflow (RDII) in the U.S has ignored this principle and most of the procedures we created generally assumed that the intrusion of RDII into sewers was uniformly distributed. After all, the prime tools for locating sources of RDII were based on CCTV and smoke testing and those tools turned up defects most everywhere.

This paper will demonstrate that measuring RDII severity is the proper first step in an RDII reduction program and the size of the initial meter basins is the 'knob' that will allow us to reveal and to take advantage of the uneven distribution of RDII in a collection system. Once the uneven distribution is exposed, the manager has only to work on the worst portions of the collection system. The 'knob' is similar to how hydraulic modelers describe the handful of settings or 'knobs' that can be twisted to bring the model into focus and replicate actual sewer performance.

BACKGROUND

Nearly everyone in the Rainfall Dependent Infiltration/Inflow (RDII) reduction business, at some time during their careers, will either ask or be asked '*what have you done with the money'*? The question commonly follows the expenditure of construction funds for a multi-year project and can be asked of a consultant or the agency's director or project manager. This question has been asked repeatedly since RDII reduction projects were formalized during the EPA Construction Grant days as Agencies were required to eliminate 'Excessive I/I' to avoid the construction of an oversized WWTP. These projects have had a sketchy history with many projects showing little removal while a smaller number appeared to show reduction. During the Construction Grant era in the 1970's and 1980's, some states would not award a grant to an agency that was predicting an RDII reduction of more than 30% as the basis for sizing a new facility. This limitation was based on the belief that higher removal rates were not possible. A grant applicant sizing a plant based on 60% RDII removal will end up with an undersized WWTP if only 30% is removed.

Many practitioners assume that the low rate of demonstrated effectiveness of RDII removal lies in the type of rehabilitation technology, the extent of rehabilitation or the presence of RDII from private sewers or building sewers. Others have concluded that ‘RDII reduction just doesn’t work’ and we should just build larger sewers and WWTP’s (transport and treat).

While the type of rehabilitation work may contribute to low demonstrated RDII reduction, it is apparent that much of the problem is due to inadequate measurement strategies. There are easily over a dozen factors that affect the measurement of RDII Reduction effectiveness, but the most important include:

- Inadequate Rainfall Measurement Strategy
- Metered Basins Too Large
- Metering Depth Drift
- Short Duration of Flow Measurement
- Error Due to Tight Subtractions
- Dynamics of Sewers (restricted)

Inadequate rainfall information and large basin sizes top the list of problems, but controlling the size of the initial flow metering basins also has the benefit of minimizing the cost of the project. Beginning an RDII reduction project by measuring flow in small and uniformly-sized basins takes advantage of the Pareto Principle, which observes that most things in life are not distributed evenly. For example 80% of a grocery store revenue will come from 20% of its items or 80% of results come from 20% of workers. It can also be shown that 80% of RDII volume originates in 20% of the collection system.

Pareto Principle in Practice

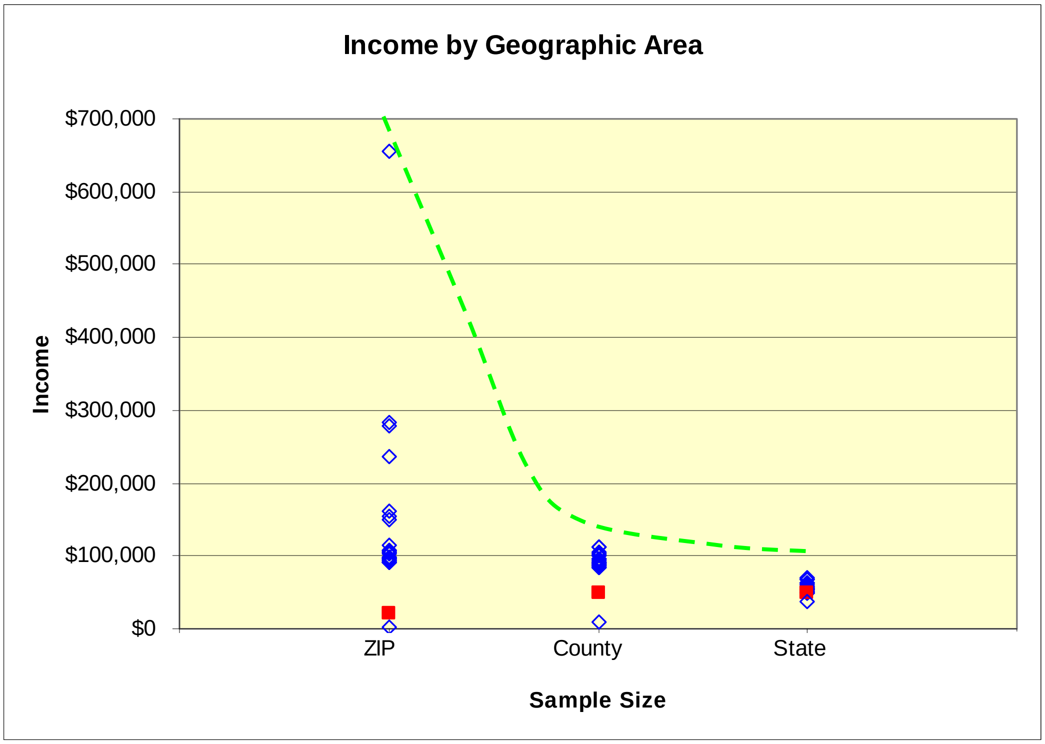
It is a well understood concept that the statistics of non-evenly distributed data differs as a function of the sample size. A good example is the income distribution of Americans. Income data are available in many forms and for this example income data are viewed in three differently-sized geographic areas (basin size). In this example we look at income data by State, by County and by Zip Code. The left group of three columns in Table 1 shows the median household income by state with the top 25 and the lowest shown. The U.S. average household median income is $50,221. The second group of three columns summarizes the household income of the country’s 3,143 counties by showing the top 25 and the lowest. The third group of columns summarizes the per capita income (median household not readily available) by Zip Code Tabulation Area for the country’s 43,194 zip codes.

Table 1 Income distribution by State, County and Zip Code

Rank	State	Household		Rank	County	Household		Rank	Zip Code Tabulation Areas	ZCTA	Per Capita
1	Maryland	$69,272		1	City of Falls Church, Virginia	$113,313		1	Montchanin, Delaware[2]	19710	$654,485
2	New Jersey	$68,342		2	Loudoun County, Virginia	$112,021		2	Houston, Texas	77010	$283,189
3	Connecticut	$67,034		3	Fairfax County, Virginia	$104,259		3	Rockland, Delaware[3]	19732	$279,424
4	Alaska	$66,953		4	Hunterdon County, New Jersey	$102,500		4	Miami Beach, Florida	33109	$236,238
5	Hawaii	$64,098		5	Howard County, Maryland	$101,003		5	Pineland, Florida	33945	$162,075
6	Massachusetts	$64,081		6	Los Alamos County, New Mexico	$100,423		6	Esopus, New York	12429	$155,540
7	New Hampshire	$60,567		7	Douglas County, Colorado	$99,522		7	Henderson, Nevada	89011	$148,899
8	Virginia	$59,330		8	Morris County, New Jersey	$96,316		8	Atherton, California	94027	$114,359
9	California	$58,931		9	Somerset County, New Jersey	$96,233		9	Boca Grande, Florida	33921	$107,297
10	Delaware	$56,860		10	City of Fairfax, Virginia	$96,232		10	Deer Harbor, Washington[4]	98243	$107,173
11	Washington	$56,548		11	Arlington County, Virginia	$93,806		11	Rancho Santa Fe, California	92067	$104,487
12	Minnesota	$55,616		12	Nassau County, New York	$92,450		12	Palm Beach, Florida	33480	$104,294
13	Colorado	$55,430		13	Montgomery County, Maryland	$92,213		13	Indianapolis, Indiana	46290	$103,347
14	Utah	$55,117		14	Calvert County, Maryland	$90,621		14	Kenilworth, Illinois	60043	$99,087
15	New York	$54,659		15	Stafford County, Virginia	$90,586		15	Beverly Hills, California	90210	$97,198
16	Rhode Island	$54,119		16	Prince William County, Virginia	$88,850		16	Greenwich, Connecticut	6831	$97,111
17	Illinois	$53,966		17	Williamson County, Tennessee	$88,358		17	Los Angeles, California	90077	$96,584
18	Nevada	$53,341		18	Forsyth County, Georgia	$88,040		18	Portola Valley, California	94028	$96,373
19	Wyoming	$52,664		19	Putnam County, New York	$88,036		19	New York, New York	10022	$95,196
20	Vermont	$51,618		20	Marin County, California	$87,728		20	Wyarno, Wyoming[5]	82845	$94,109
21	Wisconsin	$49,993		21	Charles County, Maryland	$86,141		21	Short Hills, New Jersey	7078	$92,940
22	Pennsylvania	$49,520		22	Santa Clara County, California	$85,569		22	Altamahaw, North Carolina[6]	27202	$91,666
23	Arizona	$48,745		23	Delaware County, Ohio	$85,054		23	Santa Monica, California	90402	$91,147
24	Oregon	$48,457		24	City of Poquoson, Virginia	$84,688		24	New York, New York	10021	$91,064
25	Texas	$48,259		25	Suffolk County, New York	$84,530		25	Gladwyne, Pennsylvania	19035	$90,940
	U. S. Average	**$50,221**			**U. S. Average**	**$50,221**			**U. S. Average**		**$21,587**
50	Mississippi	$36,646		3143	Kalawao County, Hawai'i	$9,333		43,194	Fish Camp, California	93623	$2,500

It is noted that although the average US median household income is the same, the range of income varies much more widely by county than by state. The zip code data are for per capita income and its range is even wider. These results are plotted in Figure 1. Red data are the average for each data set and green line shows the upper boundary of the distributions.

Figure 1 Range of Income Distribution by State, County and Zip Code

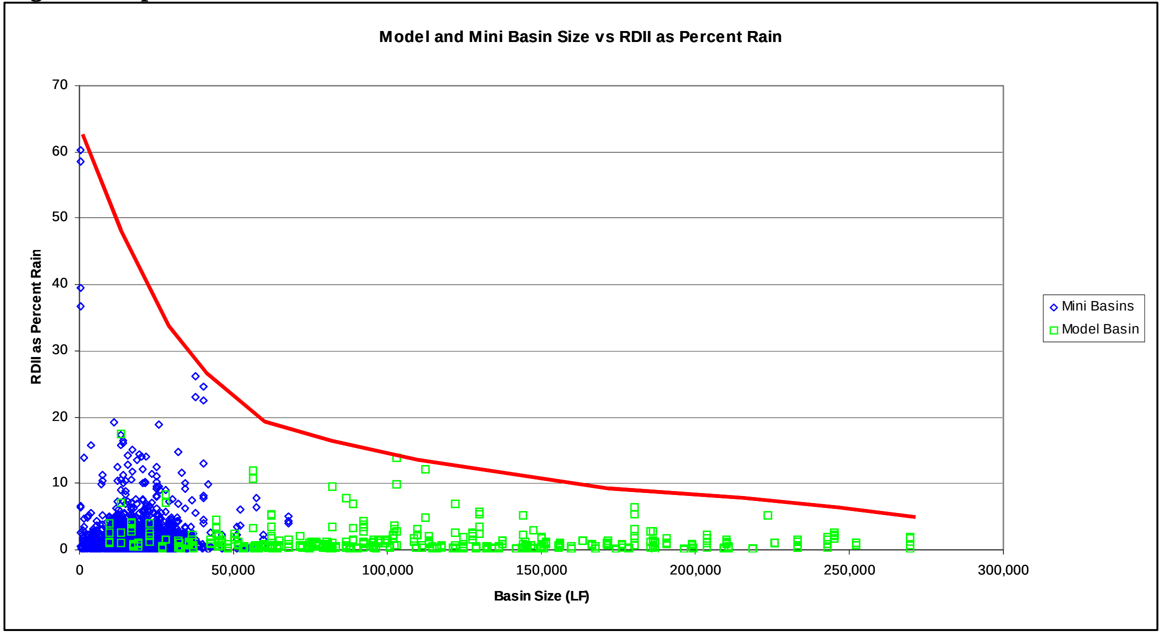


DISCUSSION

To conduct this same analysis for the RDII severity in a sewer system, the sewer system would have to be evaluated at two or more different basin sizes. Swarner showed in Figure 2 the result of an RDII study performed in King County Washington at two different basin sizes. A long term metering project was conducted on Modeling Basin that averaged around 300,000 LF in size. A short term metering program divided the modeling basins into smaller 'mini basins' of around 21,000 LF. In this study RDII severity was calculated as a Capture Coefficient or the percentage of rain volume that enters the sewer as RDII. The green data show RDII severity when the entire sewer system was divided into large modeling basins, while the blue data show RDII severity when the entire system was divided into smaller mini-basins.

The red line shows the upper limit off RDII severity and it clearly shows that the smaller basins have a wider range of severity and the upper values are higher.

Figure 2 Capture Coefficient Distribution at Two Basin Sizes.



Does the 80/20 Rule Apply to Collection Systems?

Figure 2 demonstrates that smaller meter basins result in a wider range of RDII severity and the wider range of severity is due to non-uniformly-distributed sources of RDII. However the Pareto Principle suggests that 80% of the volume of RDII will originate in 20% of the collection system. Most practitioners say that the Pareto Principle does not apply to RDII in sewers – because they have never seen it.

The program guidance during the early Construction Grants days did not provide specific guidance for the size of basins created by flow metering. The size of meter basins in that period was seldom less than 30,000 LF and typically 50,000 LF and often exceeded 100,000 LF. Often the basin size was merely result of the collection system size divided by the number of meters the consultant had in inventory.

If a flow metering provider was used for the flow metering work, the meter basins were large enough to avoid the ‘Pain of Subtraction’. If meters were placed too close to each other a negative value was often obtained (downstream meter was less than the upstream meter). This phenomenon is often referred to as the ‘Pain of Subtraction’ and is due to low precision meters, unaccounted for silt or other site hydraulic issues. The remedy for the pain of subtraction was to keep basin sizes in the 30,000 LF to 50,000 LF rang or larger so that the difference in measured flow exceeds meter error.

In the 1980’s ADS Environmental Services developed a high-precision depth sensor using a down-looking Quadredundant ultrasonic depth technology and the very small Doppler velocity sensor that allowed measurements to be made in flows less than an inch deep. ADS was both a flow metering provider and a meter manufacturer and its higher-precision meter allowed it to capitalize on the Pareto Principle by conducting RDII studies following the recipe of small and uniformly-sized meter basins.

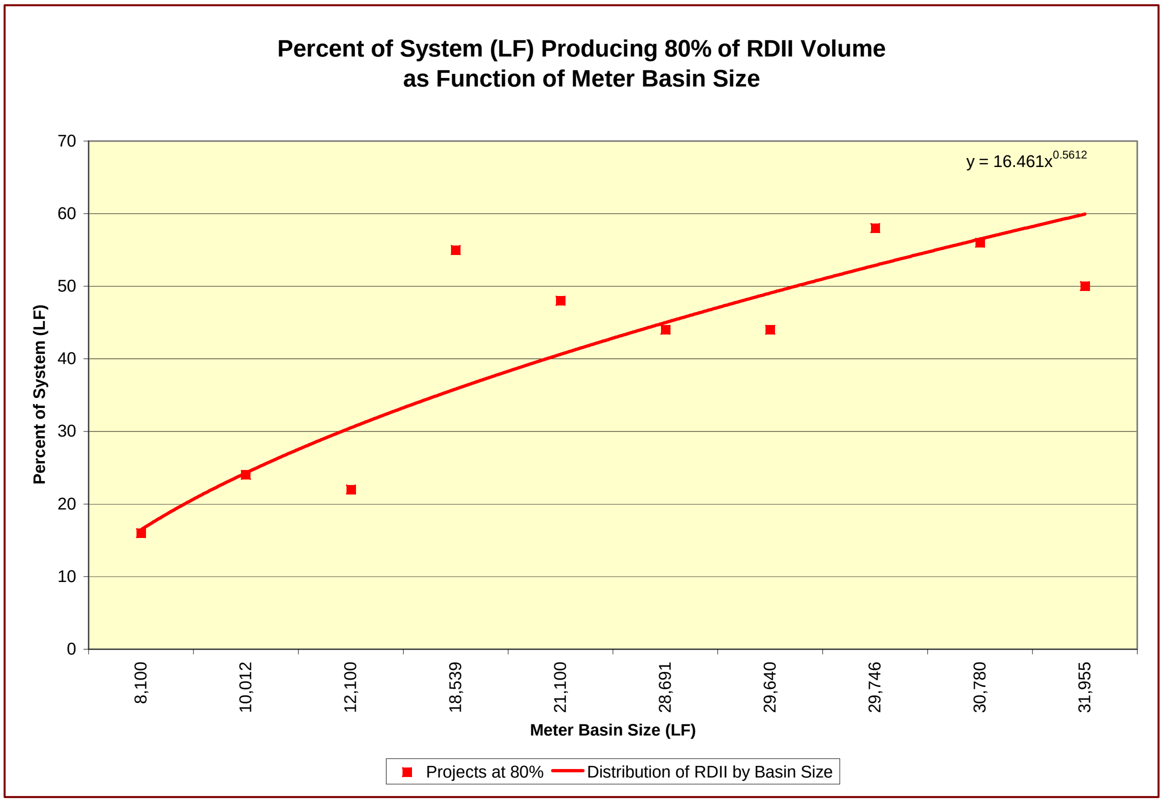
As more projects were conducted nationally with smaller basin sizes, ADS was able to conduct an 80/20 analyses for several studies. The analyses quantified the percentage of the system (in LF) that contributed 80% of the total RDII volume measured. The evaluation included several large RDII reduction projects that were conducted at basin sizes from 8,000 LF to 32,000 LF. The basin size is the average length of public sewer upstream of each flow meter. Table 2 displays the results of the evaluation.

Table 2 Supporting Data for 80/20 Analysis

Percent of System in Which 80% of RDII is found				
Project	Total System Siz	Basin Size	% Vol RDII	% System
Indiana 1	0.385 million LF	8,100	80	16
Pennsylvania 1	1.2 million LF	10,000	80	24
Pennsylvania 2	1.7 million LF	12,100	80	22
Indiana 2	1.02 million LF	18,539	80	55
Washington	16 million LF	21,100	80	48
Maryland 1	3.04 million LF	28,691	80	44
Maryland 2	2.7 million LF	29,640	80	44
Maryland 3	1.32 million LF	30,780	80	56
Maryland 4	1.67 million LF	31,955	80	50

Figure 3 is a graph of these data which shows a correlation between meter basin size and the percentage of the collection contributing 80% of the total volume of RDII. Meter basin sizes in the range of 10,000 LF demonstrate that the 80/20 rule is valid for collections systems. Meter basins in the range of 30,000 LF produce an 80/55 relationship and it is observed that much larger basins approach an 80/80 relationship. As the knob is twisted to smaller basin sizes, the problem appears to be much easier and less costly to solve. The point is to realize that rehabilitation effort can be focused on the 20% that makes a difference, instead of the 80% that doesn’t add much. Also recognize that the numbers don’t have to be “20%” and “80%” exactly. The key point is that most things in life (effort, reward, output etc.) are not distributed evenly – some contribute more than others. Also recognize that the portion of the collection system that may be rehabilitated may be greater than the 20% discussed here. A threshold of RDII severity will dictate how much of the system should receive SSES attention.

Figure 3 Basin Size is the 'Knob' that Controls the 80/20 Finding.



Non-Believers

So if this 80/20 observation holds true for collection systems, why is it that many engineers do not use it to their advantage? Most non-believers simply say that it is not true, since their experiences have never revealed it. It has also been observed and shown in Figure 3 that the effect studied in this paper essentially disappears at basin sizes larger than 30,000 LF to 50,000 LF. It is no wonder that most practitioners are skeptical about the 80/20 claim, because their RDII experience had been with larger meter basins where the effect is invisible.

Some detractors say that it is not possible to measure flow in such small basins. It is recognized that the observations and findings of the author are based on metering technology that allows flow to be measured with precision in smaller basins. As basin sizes become smaller, the flow at the most upstream basins is low and not all metering technology can function at very low flows. The technology employed by ADS' meters relied on down-looking ultrasonic depth sensors and a velocity sensor that is ½ inch high. This combination of sensors allows flow measurement in depths of under an inch. The ADS metering technology was not sold for general use until 2005 so most metering experience is based on lower precision technology or technology that requires deeper flow to operate.

Some detractors argue that getting an agency to look for RDII in this manner may cause it to overlook serious physical defects in mini-basins that do not exhibit severe RDII. The argument is that the small basin approach could lead the Owner to do no further work (CCTV) in a 'good' basin, which could have a severe physical defect. This argument contends that the proper way for an agency to maintain sewer is to use CCTV as the prime diagnostic tool and that by fixing defects, RDII will be reduced.

This argument has some validity in areas that experience little rainfall and where there is little correlation between magnitude of defect and magnitude of RDII. In most parts of the country there is strong correlation between defects and RDII and the CMOM program anticipates that an agency will conduct proactive and systematic measures of its collection systems. Flow metering certainly fulfills part of that need.

COST REDUCTION

Most modern RDII studies start with some form of flow metering followed by CCTV and perhaps smoke testing in the basin with the most severe RDII. It is evident from Figure 3 that smaller meter basins will result in isolating sources of RDII in smaller portions of the system and that less CCTV and smoke testing would be required to develop rehabilitation plans.

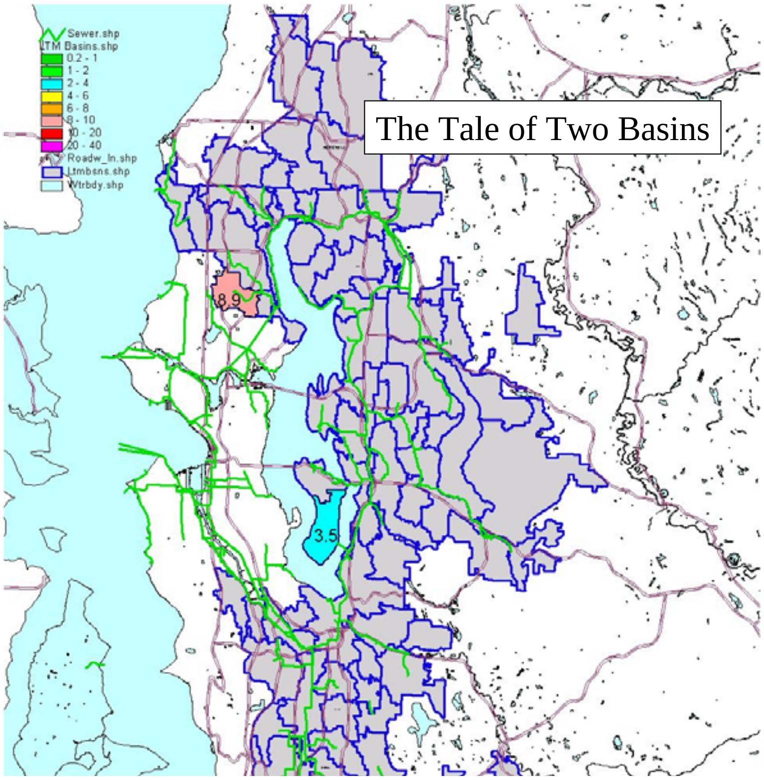


Figure 4 Capture Coefficients in Two Model Basins in King County

An example of the cost reduction comes from the King County Regional I/I Control Program in 2001. A long term metering project was conducted on Modeling Basin that averaged around 300,000 LF in size. A short term metering program divided the modeling basins into smaller 'mini basins' of around 21,000 LF.

The County had established the threshold for 'excessive RDII' as a capture coefficient of 5%. Figure 4 displays the service area with modeling basins outlined in blue. We will look at the two modeling basins labeled with the Capture Coefficient. The upper basin had a Capture Coefficient of 8.9% (excessive) and the lower basin had a Capture Coefficient of 3.5% (non-excessive). Had they conducted the RDII study with these basins, the upper basin would have undergone SSES examination and the lower basin would have been ignored.

Figure 5 compares the result of the upper modeling basin to when it was divided into mini-basins. The Capture Coefficient analysis at the model basin size is on the left and the mini-basin size on the right. Shown for each meter basin is the SSES cost estimated at $2 per LF for each basin with excessive RDII. The observation is that approximately half of the modeling basin suffered from excessive RDII. Had the SSES activity been conducted for the model basin, the SSES cost would have been approximately $600,000, but at the mini-basin level SSES cost would have been just over $300,000. The metering cost to achieve the mini-basin size was $65,000 for a savings of nearly $300,000 in just SSES activity. There would certainly be as much or more savings in rehabilitation costs, but it is difficult to develop two comparative rehabilitation scenarios.

Figure 5 SSES Effort and Cost for Modeling Basin and Mini-basins.

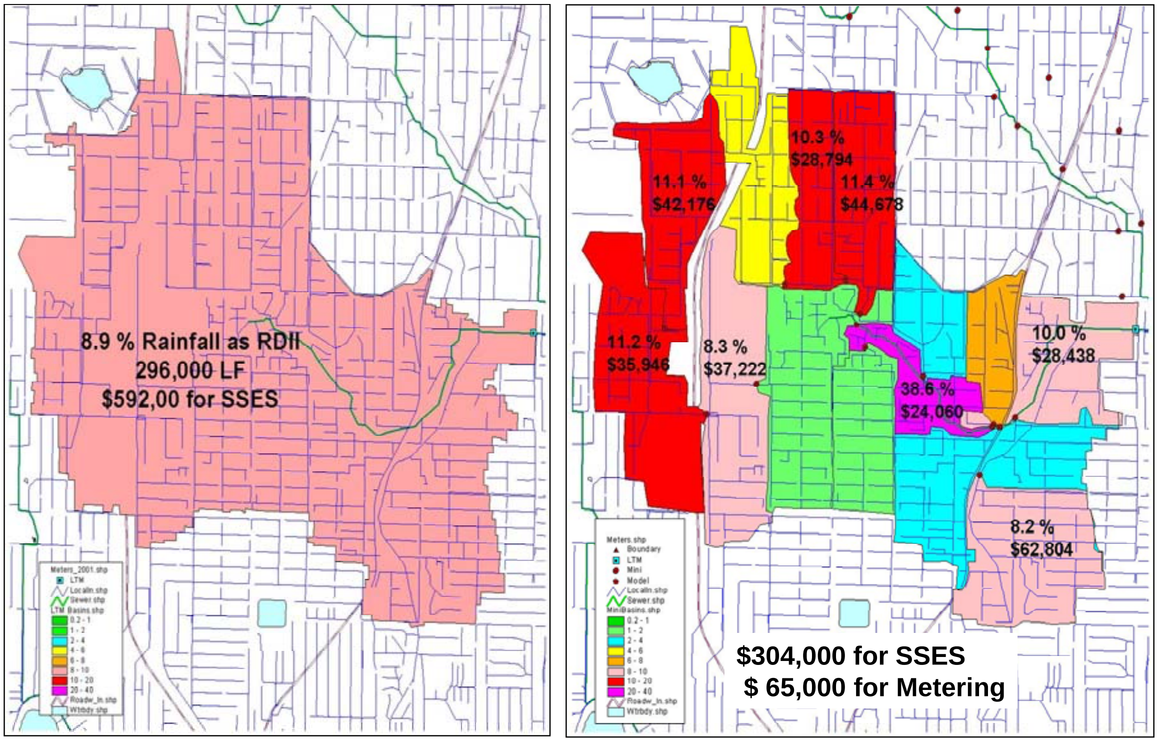
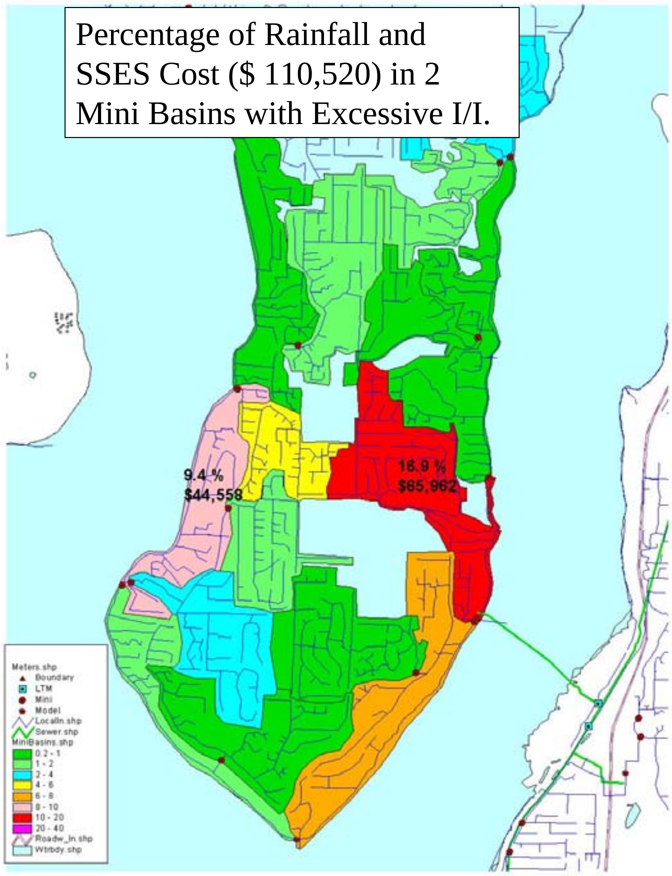


Figure 6 shows lower modeling basin compared to results at the mini-basin level. The Capture Coefficient analysis at the mini-basin size discovered two basins with excessive RDII. In this case the manager would have walked away from sources of RDII because the Model Basin was non-excessive. This phenomenon is the second problem with working with large meter basins; it is easy to miss poorly-performing sections of sewer because they are lost in the average performance of a large basin.

The third problem with large basins is the difficulty in measuring relatively small RDII reduction in basins with high flows. If the manager found these defects through conventional CCTV and smoke testing techniques and made repairs, the improvement would be statistically hard to find if the pre- and post-rehabilitation analysis was conducted on the model basin level. This phenomenon contributes to the observation that RDII reduction does not work well.

Figure 6 Two Excessive Mini-basins Existed in the Non-Excessive Model Basin



CONCLUSIONS

This paper proposes that there is a statistically-based hierarchy of decision making that should be followed to maximize the effectiveness of RDII studies and to minimize the overall cost of SSES field work and, ultimately, the cost of rehabilitating the system. Controlling the size of the meter basins used during the flow study is the first step in this hierarchy. This approach also enhances the value of CCTV and smoke testing by focusing the work on only those areas that are known to have defects.

If basin size is sufficiently small, it has been demonstrated the distribution of RDII volume will approximately conform to the Pareto Principle or the 80/20 Rule; that 80% of the RDII volume will originate in 20% of the collection system. The target basin size to approach the 80/20 rule is approximately 10,000 LF per meter basin.

The cost reduction in SSES work alone is usually greater than the cost to reduce basin size. Construction cost is also reduced because a smaller portion of the system is repaired. The second benefit to conducting a project with small basins is that it is much easier to demonstrate that RDII has been reduced. The volume of RDII reduced is easier to spot in a smaller basin with lower flows than trying to spot the reduction in a larger flow. All other things being equal, starting with small meter basins gives a person has a better chance of answering the question ‘what have you accomplished with the money?’.

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